STUDY OF THE ELECTRON EMISSION FROM THE Al FOIL SURFACE INDUCED BY α-PARTICLES IN FORWARD AND BACKWARD DIRECTIONS

A.O. VALCHUK, V.T. KUPRYASHKIN, L.P. SIDORENKO, O.I. FEOKTISTOV, I.P. SHAPOVALOVA

Institute for Nuclear Research, Nat. Acad. Sci. of Ukraine
(47, Nauky Prosp., Kyiv 03028, Ukraine)

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We studied the electron emission from the Al foil surface induced by alpha-particles from Pu^{238} in the forward and backward directions by the method of (eα)-coincidence. The angular distributions (ADs) and yields of electrons with near-zero energy e_0 and those of fast electrons e_f are measured. The ADs for e_0-electrons emitted in the both directions are sharply extended forward in the direction normal to the surface. The AD is cosinusoidal for e_f-electrons emitted in the forward direction and isotropic for those emitted in the backward direction. The yields of e_0-electrons are approximately equal if the energy of alpha-particles being the same, and those of e_f-electrons differ by a factor of 7.

Introduction

A very strong peak observed in the spectrum of electrons, which are emitted from the surface of solid radioactive sources, is known in the literature as "zero-energy peak" [1]. The intensity maximum of its energy distribution is close to an energy of 0.5 eV and its half-width approximately equals 1 eV. The intensity of emitted electrons decreases with increase of the energy so fast that it can be neglected as the energy approaches approximately 20 eV [2]. We call the electrons that make up the "zero-energy peak" as near-zero electrons and the other electrons of the spectrum as fast electrons, denoting them as e_0 and e_f, respectively. The generation of e_0-electrons is concerned with a thin layer of atoms which is on the source surface. The influence of atoms on the generation of e_0-electrons decreases at a fast rate with increase in the distance from the surface [3]. We call this thin layer of atoms (approximately 5 atomic layers in thickness) as the near-surface layer.

We suggest that the emission of near-zero electrons is caused by their dislodging from the surface due to a charge which suddenly appears in the near-surface layer [4]. This effect is analogous to that described in [5] for beta-decay. The charge in the near-surface layer can appear not only due to a radioactive decay but also due to the bombardment of a target by charged particles. Therefore, an analogous zero-energy peak is observed in the electron spectrum of solid targets being bombarded by charged particles [6].

In [4, 7], we considered thoroughly the experimental facts confirming of the mechanism of electron dislodging from the solid surface due to a suddenly appearing charge, and the present work was carried out to derive an additional confirmation of this mechanism.

1. Experimental Setup and Procedure

We call the electron emissions induced by alpha-particles coming to the target surface and coming out from it as the emission in the backward and forward directions, respectively. We investigate the emission from the Al foil surface in both directions to compare AD and the value of electron yield.

The electron emission from the target surface is investigated in coincidences with alpha-particles inducing this emission. We use Pu^{238} as the alpha-source from a spectrometric collection OSAI with an active spot of 12 mm in diameter deposited on a stainless steel substrate with $\oslash 24$ mm and a thickness of 2 mm [8].

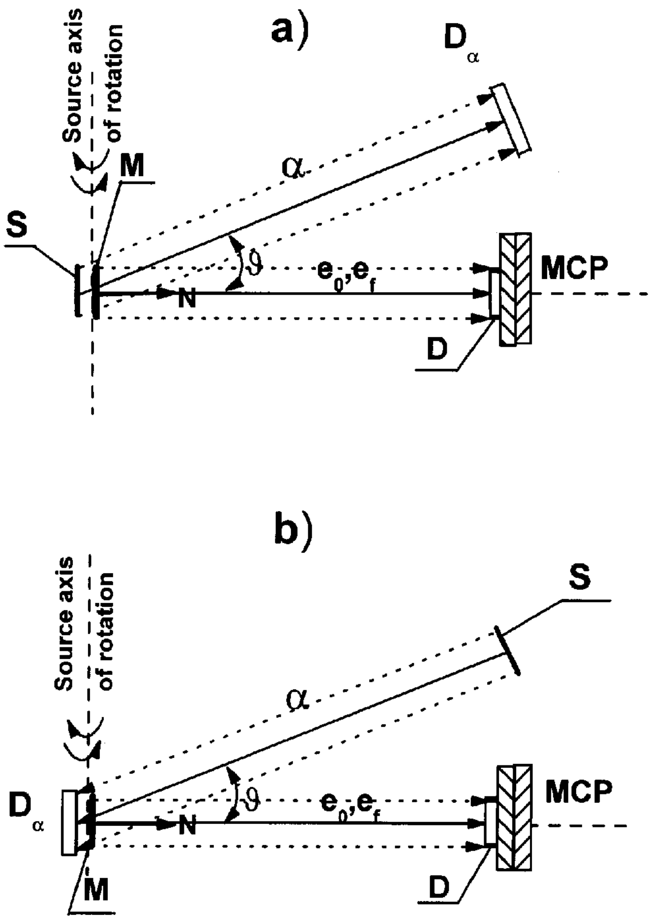


Fig. 1. Geometric arrangement for measurements of the emission in the forward (*a*) and backward (*b*) directions. S — source, M — target (Al foil), D_α — alpha-detector, MCP — chevron of two microchannel plates — electron detector, N — normal to target surface, $\vartheta = 25°$, D — aperture. The angular displacement of the target is not shown as it is in the plane which is perpendicular to the plane of the figure

To detect alpha-particles, a surface-barrier detector with n-type silicon having dimensions of ⌀24×4 mm and an active area of ⌀12 mm. A disk made of an aluminum foil with ⌀12 mm and a thickness of 10 μm is used as a target. To detect electrons, we use an assembly of two microchannel plates (MCP) in the form of a chevron with dimensions of 3×2 cm, in front of which we arrange a brass aperture with ⌀10 mm to cut down a part of the electron beam.

Both geometric arrangements for measurements of the emission in the forward and backward directions are represented in Fig. 1. To investigate the emission in forward direction, a source S is placed in the immediate vicinity of the target (a gap between them is less than 1 mm) and a distance between a target and the alpha-detector D_α is 5 cm (Fig. 1,*a*). The alpha-detector is placed at an angle of $\vartheta = 25°$ to a surface normal of the target. The source, target, and alpha-detector are rigidly bounded, and normals from the centers of their surfaces are in the same plane with the target axis of rotation. The MCP detector is fixed motionless in a chamber and placed at a distance of 4 cm from the target. The angle θ between the target normal N and the electron detector direction, which appears during a rotation of the target about its axis, is used to define the electron emission AD. This angle can be changed from –90° to +90°. To detect the backward emission (Fig. 1,*b*), the source S is interchanged with the detector D_α. Alpha-particles coming out from the target induce the emission in the forward direction, and ones coming in the target induce that in the backward direction. The same surface emits particles in the both cases of the emission in the forward and backward directions. All the system is under a pressure of $p = 2 \cdot 10^{-6}$ mm Hg.

2. Measurements and Results

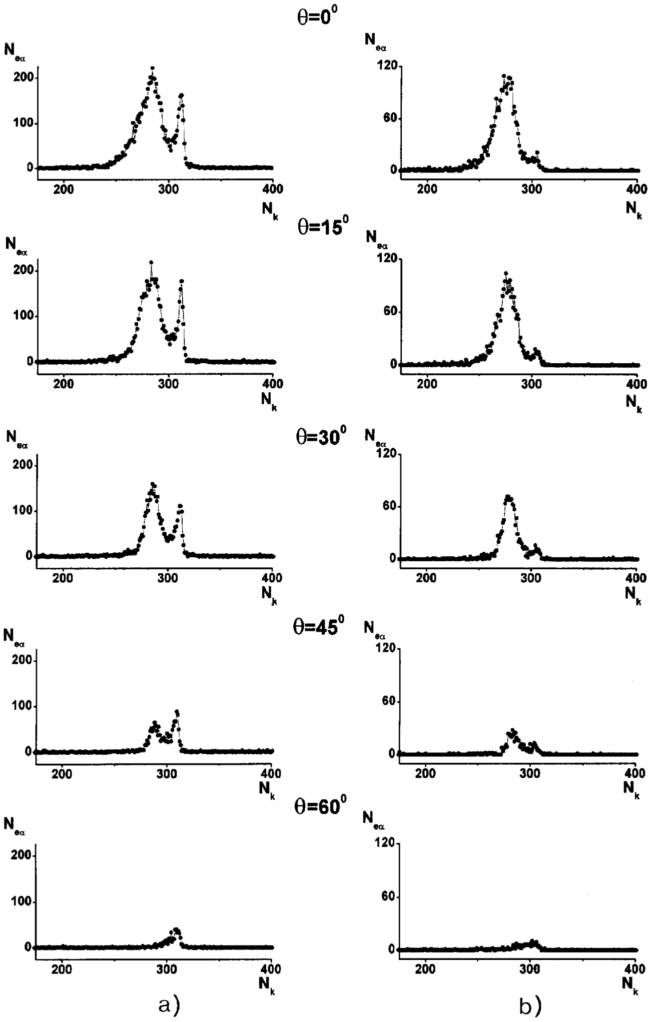
The electron emission ADs for the both directions are defined using measurements of the time spectra for electron—alpha-particle coincidences at various θ. The spectra for $N_{e\alpha}(N_k)$ are fixed using a multichannel analyzer, the time base of a channel is 0.8 ns, and the exposure time was varied from 40 min to 2 h.

The results of such measurements of the emission in the forward and backward directions are presented in Fig. 2,*a* and Fig. 2,*b*, respectively. Each spectrum includes two peaks: the left-hand peak concerns e_0-electrons and the right-hand one does e_f-electrons. The intensities of $N_{e_0\alpha}(\theta)$ and $N_{e_f\alpha}(\theta)$ are defined using the areas of peaks in the spectrum, and the probabilities of detecting are calculated as

$$R_{e_0\alpha}(\theta) = \frac{N_{e_0\alpha}(\theta)}{N_\alpha} \quad \text{and} \quad R_{e_f\alpha}(\theta) = \frac{N_{e_f\alpha}(\theta)}{N_\alpha},$$

where N_α is the number of alpha-particles fixed by the alpha-detector during the same time interval. To define the weak peaks of $N_{e_f\alpha}(\theta)$ more precisely, they were measured also in the spectra of coincidences at a voltage of 24 V on the source, when the peaks of $N_{e_0\alpha}(\theta)$ disappear due to the deceleration of e_0-electrons and the peaks of $N_{e_f\alpha}(\theta)$ remain only.

The intensity of electrons emitted from the target surface is proportional to the probability of detection.



a) b)

Fig. 2. Time spectra for electron—alpha-particle coincidences at various angular displacements θ of the target for electrons emitted in the forward (*a*) and backward (*b*) directions

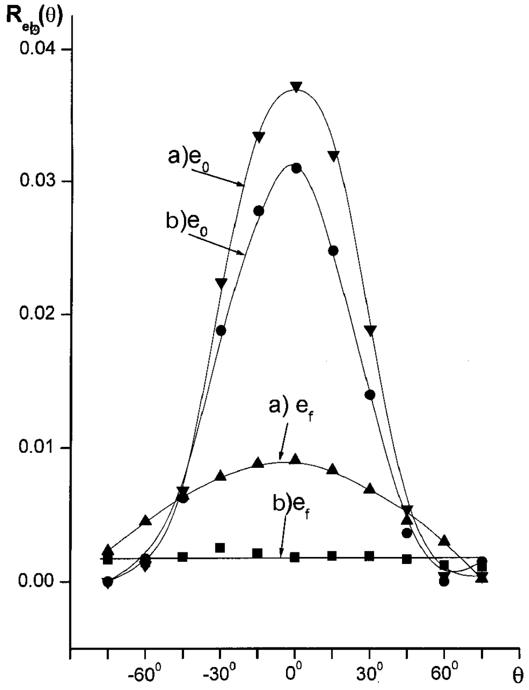


Fig. 3. Angular distributions for electrons emitted from the target measured at coincidences with alpha-particles: curve $a)e_0$ is for near-zero energy electrons emitted in the forward direction; $a)e_f$ is for fast electrons emitted in the forward direction; $b)e_0$ is for near-zero energy electrons emitted in the backward direction; $b)e_f$ is for fast electrons emitted in the backward direction

Therefore, $R_{e_0\alpha}(\theta)$ and $R_{e_f\alpha}(\theta)$ can be considered as the AD of electrons which come out from the target surface (presented in some arbitrary units). The corresponding dependences are presented in Fig. 3. The dependences $a)e_0$ and $a)e_f$ concern the forward emission, and $b)e_0$ and $b)e_f$ do the backward emission. The AD curves of $a)e_0$ and $b)e_0$ are similar and are very stretched forward due to the necessity for e_0-electrons to overcome a surface barrier, as it was already discussed in [7]. The curve $a)e_0$ is above the curve $b)e_0$ since the energy of alpha-particles coming out from the Al foil is less than that of alpha-particles coming in the foil (4 and 5.5 MeV, respectively), while the induced ionization and, respectively, the e_0-electron emission are more intensive. The curves $a)e_0$ and $b)e_0$ are similar, which is the evidence for the same nature of the e_0-electron emission for the both arrangements of the setup.

Next we consider the AD for fast electrons. The curve for the emission in the direction $a)e_f$ is cosinusoidal just as in [7] under the same geometric arrangement of the setup. The same dependence was observed in the works on investigations of the AD for true-secondary electrons [9]. The curve $b)e_f$ indicates that the emission intensity of fast electrons in the backward direction is somewhat less than that in the forward direction, while the distribution itself is isotropic. The measurements with gaseous targets carried out in [10] also reveal the isotropic recession of electrons in the back hemisphere.

To estimate the nature of the energy spectrum of e_f-electrons emitted in both directions, we measure the dependences for the $N_{e_f\alpha}$ peak intensity on the voltage supplied to the source when electrons are emitted at an angle $\theta = 0$. These dependences represent the averaged energy distribution for electrons in this spectral range. For instance, a half and three quarters of e_f-electrons

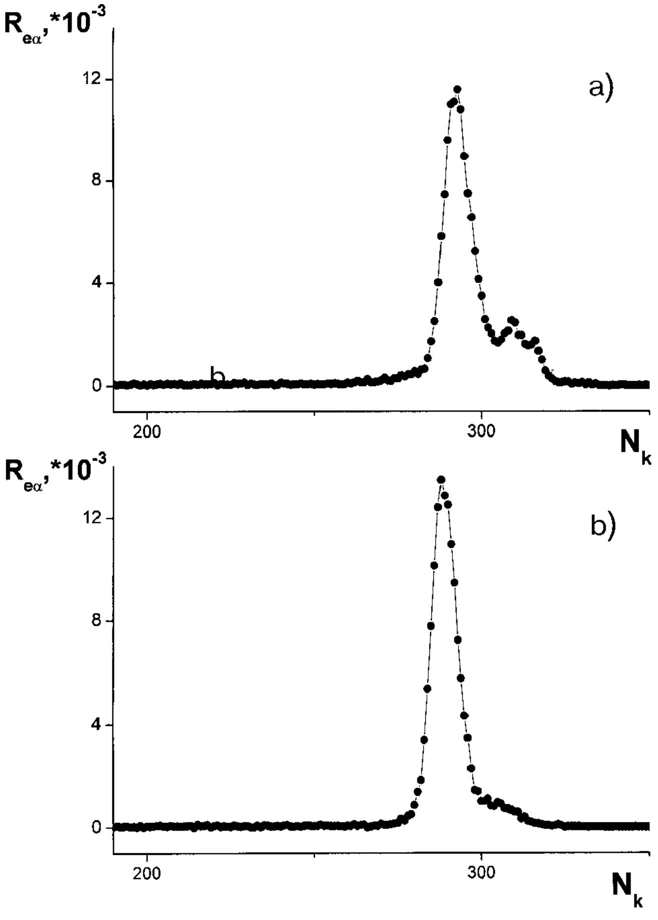


Fig. 4. Time spectra for electron—alpha-particle coincidences measured with the target of an aluminized dacron foil having a thickness of 180 μg/cm^2 at the voltage supplying to the MCP surface of +120 V for electrons emitted in the forward (*a*) and backward (*b*) directions

emitted in the backward direction have energies which are lower than 120 and 400 eV, respectively; at the same time, for the electrons emitted in the forward direction, these energies are 240 and 600 eV, respectively. The spectrum of e_f-electrons emitted in the forward direction is harder despite the fact that alpha-particles coming out from a target have lower energy than ones coming in, though the spectrum of e_f-electrons becomes harder, the alpha-particles' energy being raised. Probably, this is caused by convoy electrons.

3. Discussion

The nature of e_f-electrons emitted in the forward direction is described in detail in the review papers on the kinetic electron emission from a solid-body surface bombarded by charged particles. Therefore, we do not touch on this subject. We just make assumption about the nature of e_f-electrons emitted in the backward direction. For this purpose, we consider the reasons for the appearance of large charge when an alpha-particle is passing through the near-surface layer.

By [11], an inner-shell electron released due to ionization has low energy (< 5 eV) and cannot leave a target. But it creates a hole in a filled band. Due to the effect of Auger recombination, an electron from the conduction band fills the hole, and another electron is ejected from this band with energy of $\delta - 2\varphi$, where δ is the binding energy and φ is the electron work function. Therefore, Auger recombination results in the appearance of a charge of $+2e$ in the near-surface layer. An alpha-particle coming through the near-surface layer can cause several such ionizations n. Therefore, the total charge approximately equals $+2ne$. In the first approximation, we may consider this total charge distributed along the alpha-particle track as a point charge created somewhere in the near-surface layer. Its sudden appearance in the near-surface layer is a disturbance which causes the shake-off of electrons from the source surface [12].

Therefore, the yield of e_0-electrons from a target induced by alpha-particles can be represented as

$$Y_{e_0} \sim PWN_e,$$

where P is the probability of a single ionization event which depends on the charge and energy of an alpha-particle bombarding the target, W is the probability for the shake-off of an e_0-electron from the target surface due to the appearance of a charge of $+2ne$ (it is proportional to this charge squared), and N_e is the number of conduction band electrons which are on the surface and can be shaken off.

Probably, e_f-electrons emitted in the backward direction are those Auger electrons which are shaken off from a filled band with a spherically symmetric AD and the energy of $\delta - 2\varphi$. Hence, such electrons have to be emitted in the forward direction also. A careful examination of Fig. 3 [curve $a)e_f$] allows us to assume the presence of such electrons and their contribution in the form of a constant component to the cosine distribution, though this distribution is not obvious due to considerable difficulties of the measurements at large deflection angles of the source. Curve $a)e_f$ is slightly shifted due to an insignificant loss of symmetry during the adjustment.

To measure the time spectrum of electron—alpha-particle coincidences for the target made of an Al transparent layer deposited on a dacron film with a thickness of 180 μg/cm^2, we use a regime where a voltage of 120 V is supplied to the surface of MCP, and a large part of near-zero energy electrons is extracted by the electric field. To make it more clear, the time spectrum of electron—alpha-particle coincidences in Fig. 4 is normalized to a single alpha-particle. In this case, the energies of alpha-particles coming in the target and ones coming out are approximately equal, and the intensities of the main peaks of e_0-electrons are found to be near equal in magnitude: 0.12 ± 0.01 and 0.13 ± 0.01, while the distributions to the right from the main peaks which represent fast e_f-electrons emitted at the angle $\theta = 0$ differ in intensity by a factor of 7. Hence, the emission of e_0-electrons does not depend on whether an alpha-particle is coming in or coming out the target and also on the presence of fast convoy electrons (going with the alpha-particle). This can be easily understood if we assume that e_0-electrons appear due to a charge created in the near-surface layer by the alpha-particle, which results in the shake-off of e_0-electrons from the target surface. As for fast electrons, they create so small charge in the near-surface layer that e_0-electron yield is lower by a factor of 50 than that for an alpha-particle [13].

All the experiments carried out in the present paper with the Pu^{238} source were performed by us earlier with the Ra^{226} source (except for the $R_{e_0\alpha}(\theta)$ dependence). They confirm the results of this paper.

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ДОСЛІДЖЕННЯ ЕМІСІЇ ЕЛЕКТРОНІВ З ПОВЕРХНІ Al-ФОЛЬГИ ПІД ДІЄЮ α-ЧАСТИНОК У ГЕОМЕТРІЇ “ВПЕРЕД” І “НАЗАД”

А.О. Вальчук, В.Т. Купряшкін, Л.П. Сидоренко, О.І. Феоктистов, І.П. Шаповалова

Резюме

Методом (еα)-збігів досліджено емісію електронів з поверхні Al-фольги від α-частинок ^{238}Pu у геометрії “вперед” (на пропускання) і “назад”(на відбиття). Виміряно кутові розподіли (КР) і виходи електронів близьконульової енергії e_0 і швидких електронів e_f. КР e_0-електронів в обох геометріях різко витягнуті вперед у напрямку нормалі до поверхні мішені. КР e_f-електронів у геометрії “вперед” має косинусоїдальний, а в геометрії “назад” — ізотропний розподіл. Виходи e_0-електронів при однаковій енергії α-частинок приблизно рівні, а виходи e_f-електронів відрізняються у 7 разів.